UCRL-JC-123534
PREPRINT

First Flight of the Cloud Detection Lidar Instrument Package

J. R. Henderson, A. G. Ledebuhr, G. Cameron, P. Carter,
R. E. Hugenberger, J. F. Kordas, D. P. Nielsen, P. Stratton, B. Taylor

This paper was prepared for submittal to the
Atmospheric Radiation Measurement Program Science Team Meeting
San Antonio, TX
March 4-7, 1996

March 1996

DISCLAIMER

First Flight of the Cloud Detection Lidar Instrument Package

John R. Henderson, Arno G. Ledebuhr, George Cameron,
Preston Carter, Robert E. Hugenberger, Joe F. Kordas,
Darron P. Nielsen, Paul Stratton, and Bill Taylor

Physics and Space Technology
Lawrence Livermore National Laboratory
Livermore, California 94550

The Cloud Detection Lidar Instrument Package is composed of three instruments: the Cloud Detection Lidar (CDL) and two Wide Field of View (WFOV) cameras. The CDL can be rotated to operate in either a nadir-looking or zenith-looking mode. The WFOV cameras provide imagery to complement the CDL measurements. One camera is fixed at nadir looking and the other at zenith looking. Only one camera may be operational at a time. All instruments were successfully flown in September-November 1995.

The Instruments

The function of the CDL is the detection and profiling of high altitude thin cirrus clouds. It is designed to profile to 20 km range with a selectable range resolution down to 50 meters. The CDL detects clouds and aerosols by their backscatter return from an outgoing laser pulse.

The CDL has a mass of 28 kg, consumes 100 watts of power, and occupies <0.1 cubic-meters of volume. The main sensor assembly contains a laser diode-pumped Nd:YLF laser with an output wavelength of 1.053 μm and operating at 5 kHz repetiton rate with Q-switched 20 ns long pulses of 48 μJ/pulse. A single-photon counting Geiger-mode avalanche photodiode (APD) detector is used to detect the return signal. A stacked narrow bandpass interference filter and etalon combination generate a 0.1 nm wide filter with over 35% in-band transmission. The amplitude of the return signal provides information on the cloud/aerosol density or ground albedo. The return amplitudes are binned in 200 range bins. (The number of range bins is set by the programming to a maximum of 1024.) The distance per range bin is user-selectable in multiples of 50 m. Typically 100 m is used, giving a detection range to 20 km. A background bin equivalent to 5 km is acquired after the range bins. This is used to correct for background from ambient illumination. The range and background data are telemetered to the ground at one second intervals, along with a variety of housekeeping information used to monitor the instrument performance and status. Table 1 lists some of the parameters of the first flight instrument.

The LIDAR uses a common aperture 20 cm diameter telescope to output the transmitted beam and receive the backscattered radiation. The system is inherently eye-safe through a novel approach of operating with very low energy pulses expanded over the aperture of the telescope. Additional safety is provided by on-board interlocks and operational procedures. The system is designed to provide a measurement each second, so that the returns from 5000 separate shots are added up to increase the effective signal to noise.

TABLE 1. CDL Technical Data.

Output energy:	48 uJ per pulse (CDL-L11)
Wavelength:	1.053 um
Pulse length:	20 nsec
Repetition rate:	5 kHz (adjustable to slower)
Output aperture:	20 cm
Beam divergence:	79 urad (CDL-L11)
Beam offset (nadir):	5 +/- 0.8 deg forward of nadir
Beam offset (zenith):	3 +/- 0.8 deg forward of zenith
Detector FOV:	100 urad
Detector linearity:	1.0 (linear) to 1e6 counts/sec
System sensitivity:	0.0030 counts/photon (CDL-L11)
Bin boundary:	no lost or double-counted counts

The WFOV cameras are nominally identical. Their purpose is to provide information on the type and extent of cloud cover as well as qualitative information on the type of ground cover being overflown. The CCD cameras give a 256x256 black and white image digitized at 8 bits. The cameras have automatic gain and offset control to maximize utility of the 8-bit range. The field of view is 29.3 degrees along track and 24.1 degrees across track (rectangular pixels). Exposure time can vary from 0.5 us to 20 ms, and is short enough to avoid motion blurring of the image. Spectral response is from 350 nm to 1150 nm, peaked at 650 nm, with half-peak points at 420 and 830 nm.

The WFOV optical design was intended to give overlapping imagery when flown on a UAV. The instrument was actually flown on the Grob Egrett, which has a higher ground speed and different altitude. Overlapping imagery was obtained for parts of many of the flights when there was sufficient headwind. Images are telemetered down every 65.5 seconds. The cameras share power, control, and communications with the CDL.

Performance

The standard mode of operating the instruments was to operate the CDL in zenith looking mode for ascent, rotate to nadir looking mode for the bulk of the flight, and then rotate to zenith looking mode for descent. The nadir camera was typically operated continuously throughout the flight. Data from the instruments was telemetered to the ground and recorded there. Control commands from the ground were automated for later flights to execute the sequence above. This gave the maximum nadir looking CDL data and minimized the non-operational time during CDL rotation. There were no problems with CDL rotation despite the instrument bay temperatures being lower than expected.

Data loss for the CDL was a few percent, most of which occurred during turns where the data is of less scientific interest. The vast majority of data gaps are of a single one second data record. This has little scientific impact. During the first flight, the instrument bay temperature dropped below the operational limits and the interlocks shut the instrument off. This problem was fixed and never recurred. The range data agreed well with the radar data and pilot reports of cloud altitudes. The ground returns agreed with the reported altitudes. Detection of sub-visual cirrus was demonstrated on October 24, 1995 when the CDL had been detecting cirrus for 10's of seconds, the pilot reported cirrus ahead and the CDL signal jumped a factor of five when the visual cirrus was overflown.

The CDL was designed to have sufficient sensitivity to detect a 100 m thick thin cirrus cloud of opacity 0.03 at a distance of 20 km. For the above flight, the instrument sensitivity was estimated by plotting a histogram of ground return signal against cloud return signal. In the limit of low opacity, there is a linear relation between the two return signals. This gives a noise-equivalent opacity of 8.2×10^{-4}. Scaling the cloud distance from 2.5 km to 20 km, and the cloud thickness from 382 m (effective) to 100 m, the noise-equivalent detectable opacity is 0.014. For most of the September 29, 1995 flight, the CDL detected low clouds at 12.4 km range (~1.4 km MSL) and variable ground returns. A histogram analysis covering the non-linear region (clear skies to no ground return) gives a noise-equivalent detectable opacity is 0.014, identical to the thin cirrus results. This is two times better than the design specification.

The WFOV cameras were of great interest during the flight. They are invaluable for real time data analysis since they give immediate information on presence and extent of cloud cover. The cameras worked reliably during all flying conditions, including the low instrument bay temperatures. Approximately half of the images were corrupted by telemetry problems. Approximately one-third of the corrupt images could be repaired by inspecting the image to determine dropout location, and adding pixels to repair the defect. The value of the added pixels is determined by neighbor averaging. The format of the WFOV image transmission has been changed to isolate the effects of telemetry errors. We expect that the next flight series will have only a few percent of the images lost or noticeably corrupted. Under certain lighting conditions, the CCD generates a vertical stripe on the image. This is easily removed in post processing and typically leaves no noticeable artifacts.

Results

Figure 1 shows the CDL results for part of the 30-Oct-95 flight. Data before and after instrument rotation are shown. There is a high thin cirrus layer and an opaque low cloud layer. Figure 1 has been thresholded for printing purposes. The raw data and color plots show much greater information about cloud structure and the extent of thin cloud features. For elevation plots, the CDL range data is converted to aerosol elevation data by utilizing data from other instruments to correct for the aircraft attitude and altitude. The ground return signals come out at the correct altitude for both level flight and turns, validating the range-to-altitude conversion algorithms.

Figure 2 shows a WFOV image showing broken clouds, the ground, and the cloud shadows on the ground.

A cloudiness indicator "cloudy" is derived from the CDL data by picking the largest return signal in the 0.6 km to 20 km elevation range for each one second record. This indicator can be used in a quantitative manner to estimate cloud opacity and the likelihood of ground radiation passing through the cloud.

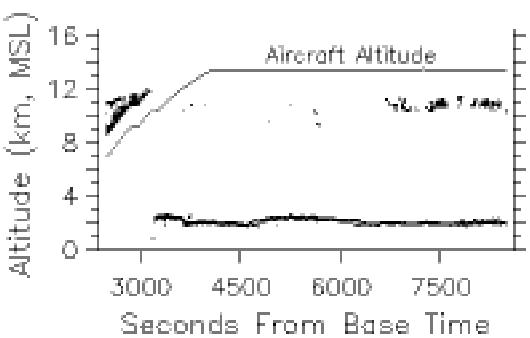

Figure 1. 30-Oct-95 CDL data converted to elevations. The data have been summed to 20 second intervals. The points displayed are range bins with a S/N greater than 10. The upper line is the aircraft altitude. Note that the cirrus at 11 km are detected from below before 3175 seconds and from above after 3640 seconds. The clouds at 2 km are only detected from above in this plot. Down-to-up rotation took 55 seconds.

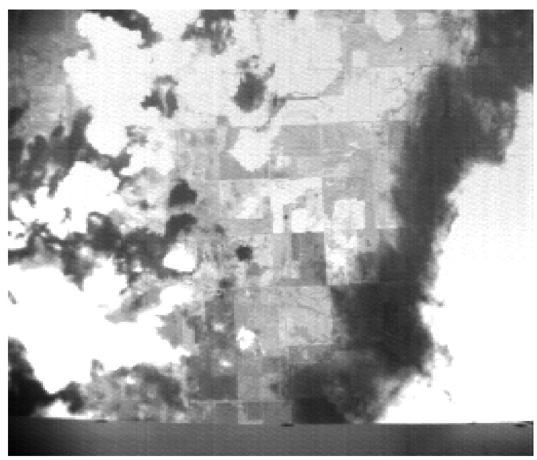

Figure 2. Nadir WFOV image showing the ground, clouds, cloud structure, and cloud shadows. The band across the lower edge of the image is the window edge of the instrument bay. The cloud shadows are about 1/4 frame "above" the clouds in this image. (29Sep95, 18:13:16 GMT.)

Acknowledgments

This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Technical Information Department • **Lawrence Livermore National Laboratory**
University of California • Livermore, California 94551